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PROPERTIES OF HIGH NITROGEN STEELS PRODUCED BY HIGH PRESSURE GAS ATOMIZATION

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Abstract

The production of metal powders by inert gas atomization typically combines at ambient pressure in a metal chamber and atomizing a fine stream of liquid metal from the melt chamber with powerful streams of gas into an atomizing chamber also at ambient pressure. In a pilot plant production unit, a series of Fe-Cr-Mn-Ni alloys were melted and atomized under pressure to achieve high nitrogen contents in the atomizer powder. Nitrogen contents between 0.5 and 1.3 wt. percent were achieved. Three Fe-Cr-Mn-Ni alloys were atomized under pressure and consolidated by hot extrusion. Tensile properties were determined after consolidation and heat treatment and were related to the nitrogen content and microstructure.

Introduction

Nitrogen, like carbon, is a very potent interstitial solid-solution strengthening element in austenitic stainless steels [1,2]. Alloying with nitrogen offers unique challenges since the solubility of nitrogen in liquid-Fe and Fe-based alloys is limited at atmospheric pressure. However, nitrogen solubility can be increased by increasing the nitrogen gas pressure above the melt and through alloying additions. From a processing and alloy design viewpoint, nitrogen steels are distinct and offer significant challenges. A steel should be considered "high-nitrogen" if it contains more nitrogen than can be retained in the material by processing at atmospheric pressure. For most austenitic materials, this limit is about 0.4 wt% [3].

Recently, a pressurized gas atomization system capable of producing stainless steels with nitrogen concentrations in excess of 1 wt. percent was developed [4]. The powders were produced in a production inert gas atomizer with a melt capacity of 300 lbs. The melt chamber was maintained at a nitrogen pressure of 150 psig and the atomizing chamber at 100 psig. Powder yields from the process were in the range of 200-250 lbs. per heat. Three Fe-Cr-Ni-Mn compositions were melted under pressure, atomized, and the product powder consolidated by hot extrusion. The consolidated material was evaluated for nitrogen content, tensile properties, and microstructure.

Results and Discussion

Three Fe-Cr-Mn-Ni compositions based on a modified type 201 austenitic stainless steels were melted. The compositions and nitrogen contents achieved are shown in Table I.

Table I: Compositions of Modified 201 Stainless Steel Alloys Produced by Pressurized Gas Atomization

Alloy	Fe	Cr	Ni	Mn	Nb	C	N	O
201A	Bal.	17.2	4.1	5.5	- - -	0.058	0.56	0.25
201B	Bal.	16.6	4.7	6.5	- - -	0.030	.078	0.09
201Nb	Bal.	16.8	4.4	6.5	0.59	0.021	1.35	0.38

The alloy compositions are high in Cr and Mn and low in Ni to improve solubility of nitrogen. The production runs were satisfactory but high pour rates necessitated by the melt and atomizing chamber pressure differential led to high nozzle erosion in the 201A and 201 Nb heats. The high metal pour rate (due to nozzle erosion) also led to higher exhaust gas temperatures than anticipated. The higher than normal exhaust gas temperatures degraded piping seals and led to higher oxygen levels in these two heats. Figure 1 shows the calculated nitrogen solubilities at 1 atmosphere and 10 atmosphere pressure compared with the actual solubilities achieved.

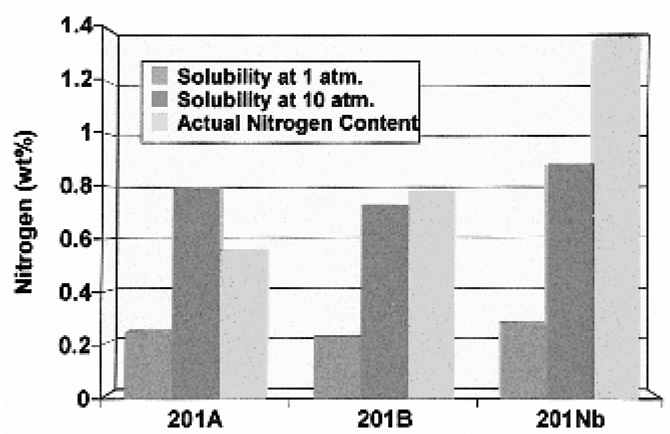

Figure 1: Calculated solubilities for three alloys compared with actual solubilities achieved.

Actual nitrogen content was greater in the 201 Nb alloy than the calculated nitrogen solubility due to the presence of NbN and Cr N nitrides formed in the melt. These nitrides do not re-dissolve completely during subsequent annealing.

Tensile testing of the three alloys and microstructural examination were conducted on as-extruded material and on extruded material that was solution annealed for 1 hour at 1100°, 1150° and 1200°C. The grain size of the consolidated powders in these three conditions is shown in Table II.

Table II: Grain size of as-extruded powder and after solution anneals for 1 hour at 1100°, 1150° and 1200°C.

Alloy	As-Extruded	SA 1100-1	SA 1150-1	SA 1200-1
201 A (0.56 N)	**< 7. 5 μm**	**< 7.5 μm**	**8 - 12 μm**	**25 - 30 μm**
201B (0.78N)	**< 7. 5 μm**	**10 -15 μm**	**15 -20 μm**	**25 - 30 μm**
201 Nb (1.35N)	**< 5 μm**	**< 5 μm**	**5 -10 μm**	**10 - 15 μm**

An x-ray analysis of phase present in the as-extruded and solution annealed material is shown in Table III.

Table III: Phases detected in as-extruded alloys and in alloys solution-annealed for 1 hour at 1200°C.

Alloy	Nitrogen (wt%)	As-Extruded	Annealed (1200°C - 1 Hour)
201A	0.56	Austenite Cr_2N $Mn(Al,Si)_2oO_4$	Austenite $Mn(Al,Si)_2O_4$
201B	0.78	Austenite Cr_2N $Mn(Al,Si)_2O_4$	Austenite $Mn(Al,Si)_2O_4$
201Nb	1.35	Austenite Cr_2N $Mn(Al,Si)_2O_4$ CrN, NbN	Austenite $Mn(Al,Si)_2O_4$ CrN, NbN

In alloys A and B, fine Cr_2N precipitates refined by extrusion are observed. These dissolve during solution annealing leading to grain growth (Table II). In the Nb containing alloy CrN and NbN, precipitates are observed that do not go back in solution and limit grain growth. $Mn(Al,Si)_2O_4$ is present from nozzle erosion during atomization.

A comparison of yield strength for the as-extruded and the annealed alloys is shown in Figure 2. Yield strength increases with nitrogen content. There is a spread in the yield strengths of solution-annealed materials due to variations in grain size (see Table II).

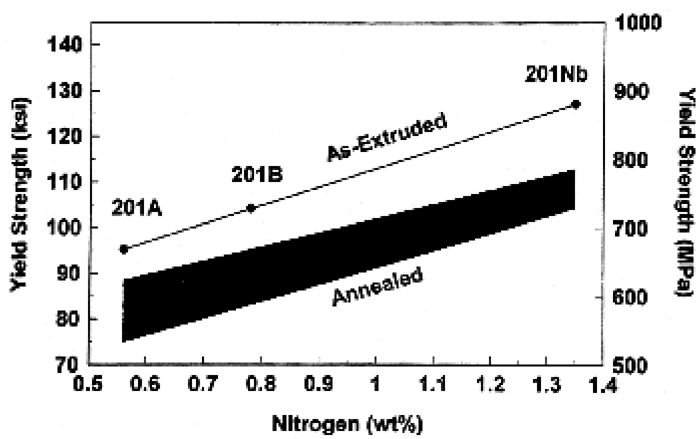

Figure 2: Yield strength vs. Nitrogen content for as-extruded and solution annealed alloys.

The ultimate tensile strengths and ductility of the nitrogen steels are shown in Figures 3 and 4 respectively**.**

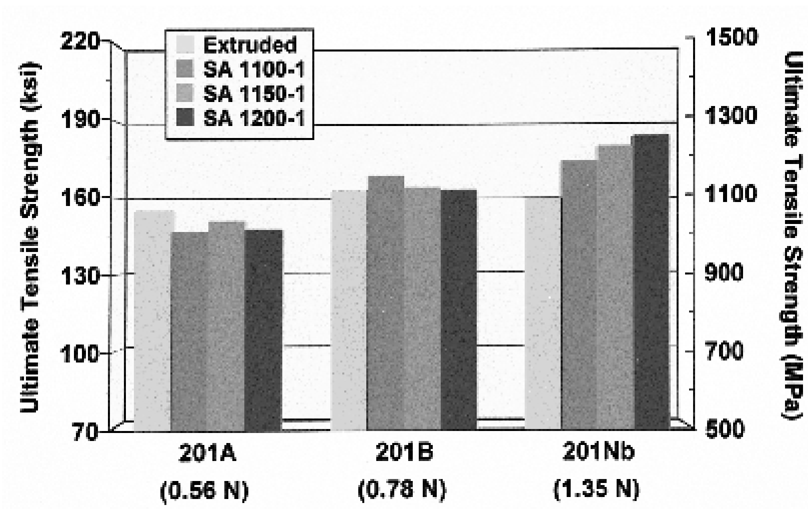

Figure 3: Ultimate tensile strength of nitrogen steels

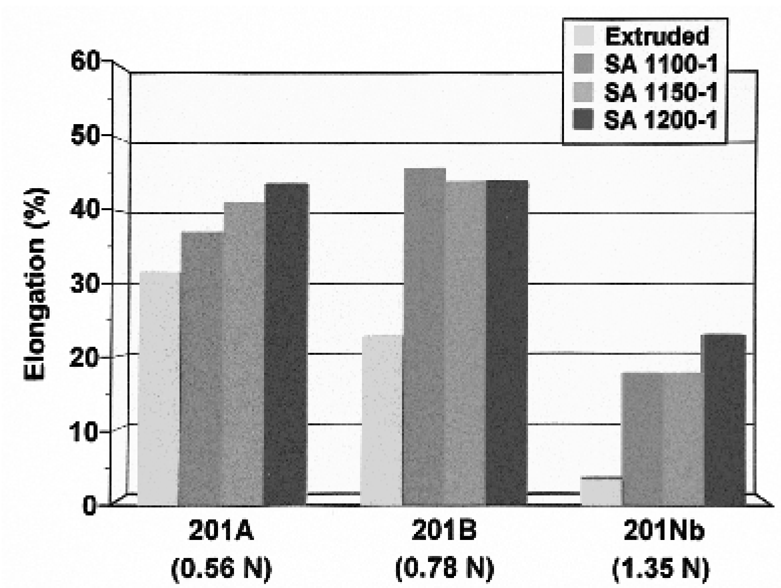

Figure 4: Elongation of consolidated powders in the as-extruded and annealed condition.

It is apparent that the ultimate tensile strength of solution treated alloys is not as affected by grain size as the yield strength. The UTS of the 201 Nb alloy increase with annealing temperature since some embrittling grain boundary nitrides do re-dissolve. The ductility of all the alloys increases as grain boundary and intra granular Cr_2N is re-dissolved. In the 201 Nb alloy, insoluble nitrides limit ductility of the as-extruded and the solution treated material compared to alloys A and B.

Summary and Conclusions

Nitrogen is an effective interstitial solid solution strengthener of austenitic stainless steels. It is more effective than carbon. This paper describes a high pressure gas atomization production process for high nitrogen powders. This potentially allows for high volume production of powders without a high initial capital investment.

In consolidated and solution heat treated alloys excellent yield strengths were achieved. Yield strengths increased linearly with nitrogen content. Figure 5 shows the yield strength variation with nitrogen content for a number of austenitic steels. Both as-extruded and solution annealed powder metallurgy (P/M) alloys fell within the anticipated band of yield strengths with respect to their nitrogen contents.

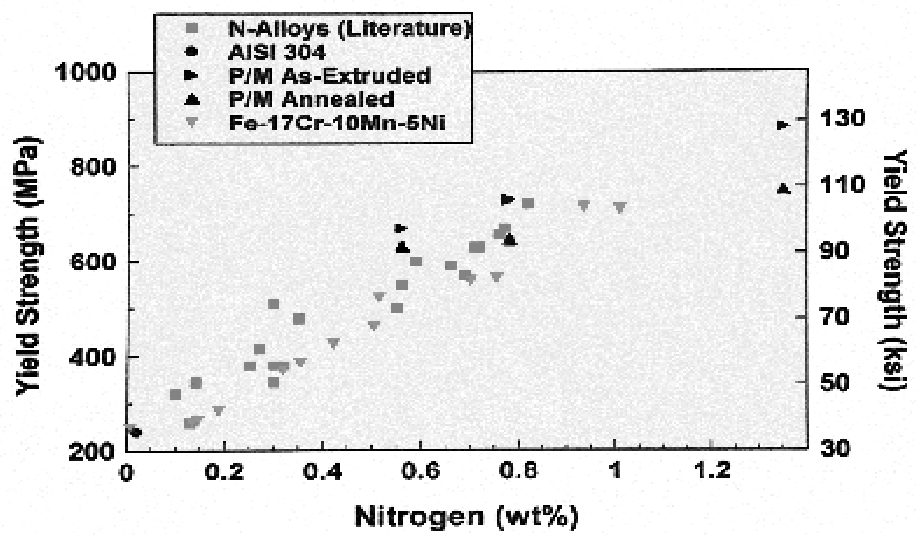

Figure 5: Yield strength vs. Nitrogen content for various austenitic stainless steels.

References

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